ULTRAVIOLET ABSORPTION IN THE CONTINUOUS SPECTRUM OF JUPITER[1]

V. D. Krugov

ABSTRACT: The results of the spectrophotometric investigation of Jupiter (range 3300-4800 Å) for the purpose of determining ultraviolet absorption for different regions of Jupiter's disk region are presented. The observations were made with a 70-cm reflector and ASP-7 spectrograph (dispersion 230 Å/mm at H and K). About 100 spectrograms were taken during 1969 (January-April). It is shown that ultraviolet absorption in Jupiter's atmosphere is real and the quantity of effect for positions of the spectrograph's vision slit 1, 2, 3, 5 (as shown in Figure 2) is an average lg I(0.33) - lg I(0.48) = -0.33. Time variations are observed in the course of reflectivity for different regions of Jupiter's disk. The quantity of ultraviolet absorption is approximately the same for Jupiter's northern and southern polar regions (range 4800-3300 Å).

A Short History of the Question

Many authors have obtained chromatic photometry of the planets in the solar /9 system, particularly of Jupiter and Saturn, in the past 40 years. This originally was in the form of visual and photographic measurements, followed by spectrophotometric measurements, but it was not until recently that photoelectric measurements were obtained. N. P. Barabashov and A. T. Chekirda [1] were among the first to obtain spectrophotometry of Jupiter, and of other planets.

Jupiter's spectrum was photographed with an objective prism on a 6-inch reflector (focal length of the objective lens was 55 cm). The aperture in the objective prism was 110 mm, and the angle of refraction was 12°. Three spectrograms, measurement of which was made with a Hartmann microphotometer, were obtained for Jupiter. Measurements were in the 4100-6000 Å region. The results showed a slight drop in intensity from 6000 to 5000 Å, and a sharply defined drop in intensity in the 5000-4100 Å region. The work was done at the Astronomical Observatory of Khar'kov State University in 1948.

V. G. Teyfel' [2], in 1959, used an ASP-9 slit spectrograph (dispersion 143 Å/mm at H_γ) on a 200-mm AZT-7 mirror-lens telescope to obtain the spectra

---

1. Figure 8 is an appendix and illustrates the relative spectral energy distribution for different regions of Jupiter.

of the equatorial (EZ) and temperate zones of Jupiter, north (NTZ) and south (STZ). The spectrograph slit was 0.050 mm wide and cut out a band $\varphi = \pm 12°$ in the focal image of Jupiter's disk in the equatorial zone, and one approximately $\varphi = 30\text{-}60°$ in the temperate zones. Thirty-two spectrograms were obtained and measured to make a photometric study of the continuous spectrum. Spectrograms of the Moon in the Mare Vaporum region were obtained in May 1959, in order to complete the photometric closure of Jupiter's spectrum.

A drop in the intensity to 0.10(lg I) [2] will be observed in the spectral distribution in the 3900-500 Å region. Some authors find strong ultraviolet absorption, others find none [2].

Two series of spectrograms of Jupiter and of the Moon were obtained with this same telescope in 1962 at the Astrophysical Institute of the Academy of Sciences of the Kazakh SSR [3]. The author provides a curve that shows quite clearly just how precipitous is the drop in intensity in the UV region of Jupiter's spectrum. Intensification of absorption in the spectrum begins at 4100-4200 Å, and near 3600 Å the effect achieves a magnitude of 0.36(lg I), where $\lg I = \lg I_J - \lg I_M$. Observations were made on 13-14 September, and again on 11-12 October 1962. Different photometric gradients were obtained for these dates, but these differences were less than those between the observations made by V. G. Teyfel' and those by the Kiesses and Corliss [4].

V. G. Teyfel' has no doubt that there is strong UV absorption in Jupiter's spectrum. It appears that here we have a matter of the absorption of aerosol in Jupiter's atmosphere. The spectrograms of Jupiter's dark equatorial band and light temperate zones obtained by V. G. Teyfel' on 20-21 November 1962, showed no significant differences in the behavior of the spectral reflectivity of these regions in the UV region. So we cannot say that strong UV absorption is inherent only for the material of the dark or light zones of the planet. /10

I. N. Glushneva [5] investigated the dependence of Jupiter's monochromatic albedo in the 4500-3200 Å region of the spectrum in 1963. The spectrograms were obtained with an ASP-5 slitless spectrograph at the P. K. Shternberg State Astronomical Institute, a high-mountain station. The dispersion at H_γ was 150 Å/mm, at 3000 Å - 50 Å/mm. The observations were made in January-February 1963, and 10 spectrograms of Jupiter were obtained. Comparison spectra of the

planet and of stars were photographed at identical zenith distances to preclude the influence of absorption of light in the Earth's atmosphere. No direct comparison of spectra of planet and Sun was made; instead the Sun's spectral energy distribution was taken from Johnson [12]. Jupiter's monochromatic albedo decreases by a factor of 1.5 in the interval 3900-3500 Å. The albedo begins to increase with further shortening of the wavelength. Comparing the results obtained by Younkin [6] and Glushneva, we can conclude that the behavior of the albedo, according to Younkin, can be characterized by a monotonic decrease, and this is different from the results obtained by I. N. Glushneva.

According to I. N. Glushneva, the sharp reduction in the albedo begins at 4100-4200 Å. Increase in the albedo in the region shorter than 3500 Å obviously is real because it is obtained by comparing Jupiter with α Lyrae and α Ursae Majoris.

V. F. Kartashov [7] made observations in August 1965, and studied UV absorption in Jupiter's spectrum, using a slit spectrograph with a dispersion of 143 Å/mm on an AZT-7 mirror-lens telescope. The spectrograph slit was oriented in the plane of the planet's equator (width 0.05 mm). Data on solar energy distribution were taken from I. N. Glushneva [5]. If the gradients obtained for the entire period of the observations are compared, one notes the variations in Jupiter's gradient in the ultraviolet. We therefore can conclude that the time-dependent change in the relative spectrometric gradient is real.

V. V. Avramchuk [8] too made a spectrophotometric study of Jupiter. His observations were made at the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian SSR in 1965, using a 70-cm reflector in the Cassegrain focus (F = 30 m) with an ASP-21 diffraction-grating spectrograph. Jupiter's spectrograms were tied in with stars with known energy distributions.

When orientation of the spectrograph slit was along the central meridian it was found that there was a reduction in the albedo toward the UV end of the spectrum for all zones of Jupiter investigated. Minimum absorption in the UV rays was observed in the polar regions of the planet, and the maximum in the northern, light, tropical zone. The observations were made on 27-28 August 1965. The periods 25-26 January 1965, and 12-13 February 1965, can be characterized by absence of UV absorption. Nevertheless, the polar regions were more "blue" than

the equatorial regions at these times.

The author concludes that UV absorption is variable and can cause the changes observed in the color of Jupiter. The absorption is not associated with light or dark bands, but is global in nature, increasing toward the center of the disk. Younkin [6] used the 60-inch telescope with scanning monochromator at the Mount Wilson Observatory for photoelectric investigations of UV absorption in 1961. An RCA 1P21 photomultiplier was used to record the spectrum in the 3300-5200 Å region, and an RCA 7265 photomultiplier was used for the same purpose in the 4800-8000 Å region. Observation conditions were such that the investigations in these two regions had to be made on different nights. Direct measurements of the solar spectrum were not made, so Johnson's data [12] were used for the 4100-8000 Å region, and Shkol'nik's data were used for $\lambda < 4100$ Å. Overlapping of spectral intensity curves for Jupiter was in the 4800 and 5200 Å /11 regions. The slit was positioned near the center of the planet's image.

The spectral energy distribution curve obtained for Jupiter can be characterized by the monotonic reduction in the albedo in the UV region of the spectrum and the attainment of a value of 0.25(lg I) in the 3300-4800 Å region.

Jupiter's spectrum was measured, including that of the UV region, in January and September 1967, by Isakson [9], who used a monochromator with 16- and 36-inch telescopes. A synchronous motor, running at a speed of 250 Å/min, was used to rotate the scanner grating. Numerous observations were made with a 20" entrance slit and an 80 Å exit slit. The principal purpose was to determine the relationship between the reflectivity and the wavelength of the continuous spectrum. This was because of the spectrometer's low resolution. The slit was oriented with respect to the center of the planet's disk. A direct comparison between the planet's spectrum and that of the sun was difficult, so observations of Jupiter were standardized with respect to the stars most nearly resembling the sun in spectral class.

The author posed for himself the task of obtaining the relationship between the mean reflectivity for the planet, and the wavelength. Possible temporary variations in this relationship were not studied.

Isakson's data show the following peculiarities in Jupiter's spectral energy distribution. An energy minimum, such that lg I(3750) - lg I(4800) = -0.23,

is observed in the 3750 Å region. Some increase in the albedo is observed beyond this wavelength. These results differ somewhat from those in references [5, 6]. Isakson tends to believe that these differences are the result of study of different sections of the planet's disk.

Irvine's paper [10] contains the results of photoelectric investigations of Jupiter and Saturn in 1963-1965. The observations were made with 10 interference filters in the 3150 Å - 1.06 micron region, as well as in the UBV system. The observations were made through the 16-inch telescope at the Bowden Observatory in South Africa, and through a 12-inch telescope in France. Stars with known energy distributions were measured for each filter. Phase curves for Jupiter, and for its geometric albedo, were obtained. Irvine's data, when plotted, failed to show a maximum at 4000 Å, or a minimum at 3500 Å, on Jupiter's spectral energy distribution curve, as had been the case in I. N. Glushneva's paper [5]. What can be observed is a smooth drop in energy toward the UV end of the spectrum such that lg I(3300) - lg I(4800) = -0.24. Hopkins and Irvine [11] studied the variations in Jupiter's spectral energy distribution as they analyzed their data and concluded that the annual and monthly variations were, as a whole, insignificant. There are variations from date to date, and this has been noted repeatedly by other authors. Table 1 lists the values of the magnitude of the UV absorption effect as derived by the different authors.

TABLE 1. VALUES OF THE MAGNITUDE OF THE UV ABSORPTION EFFECT

Year	Author	λ	$\lg I(\lambda) - \lg I(4800)$
1948	N.P.Barabashov		
	A.T.Chekirda	0.41	—0.16
1961	L. Younkin	0.33	—0.25
1962	V.G. Teyfel'	0.36	—0.35
1963	I.N.Glushneva	0.33	—0.13
1963—1965	M. Irvine	0.33	—0.24
1967	M. Isakson	0.33	—0.14

If one disregards the intensity minimum near 3600 Å for some observations, the data in Table I are such that one can say there is quite a great difference in the magnitude of the absorption effect in the 3300-4800 Å region. /12

What follows from this survey of the work in the field of spectrophotometry

of Jupiter in the shortwave region of the spectrum is that there is UV absorption in Jupiter's atmosphere, and this has been noted by many authors. The magnitude of this effect has different values during different periods of observation. However, the variability of this effect stems from the difference in the observations, each of which is burdened by its own systematic errors. Unfortunately, it is impossible to cite a single study (with the possible exception of Irvine's) in which the fact of the variability of Jupiter's UV absorption could be established with complete reliability. Nor is there any evidence to establish a behavior pattern in the variations in the absorption effect. Some researchers associate the variability in UV absorption with solar activity, others with change in the planet's atmosphere. It is obvious that all these questions can be answered only by lengthy, systematic, observations using a unified procedure.

Statement of the Problem

The results of the majority of the work done to study UV absorption in Jupiter's atmosphere are based on data obtained over several nights, or over a period of one or two months. Then too, all the observations listed in the survey refer to the planet as a whole, or to the central region of its disk. Still not understood is how UV absorption is distributed in terms of the planet's disk, although some observers have noted a different energy distribution for polar and central regions. In no case has this author found a single paper based on the results of systematic, simultaneous, investigation of UV absorption by Jupiter for the central and limb regions of the disk (polar regions, east and west limbs).

Yet investigations such as these are of great interest, particularly in connection with established disk and time-dependent variations in the intensity of the molecular CH_4 and NH_3 absorption bands [14]. It can be anticipated that if the variation in the intensity of the CH_4 and NH_3 molecular bands is associated with change in aerosol diffusion properties, it also can cause a change in UV absorption.

High dispersion spectrographs are not needed, obviously, to investigate UV absorption and determine its magnitude at different times. On the contrary, systematic work on UV absorption for different regions of Jupiter's disk can be more effective if low dispersion equipment is used, permitting observations to be made at short exposures for all regions of the disk.

Our goal was to conduct long-term, systematic, monitoring of the spectral energy distribution for Jupiter and Saturn in the shortwave region of the spectrum, using the 70-cm reflector and the ASP-7 spectrograph at the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian SSR. Observations were begun in January 1969. The program was to last for several years. Some 100 spectrograms of different regions of Jupiter's disk for the period January-April 1969, have been obtained.

Equipment and Observation Procedure /13

The observations to determine the magnitude of the UV absorption in different regions of Jupiter's disk were made using a 70-cm reflector in the Cassegrain focus (F = 10.5 m) and a prism spectrograph that could be rotated around its axis by a position bearing. The spectrograph was usable at 3000-7000 Å, and slit limits were 0.001-0.4 mm. The spectrograph's linear dispersion at 3000 Å was 90 Å/mm, and 230 Å/mm near the H and K lines. Plotting of a dispersion curve was a requirement for the work. An iron arc spectrum was obtained for this purpose, as was that of the Sun, for great certainty. We identified 11 absorption lines very nearly uniformly located in the 3300-4800 Å region and constructed the dispersion curve in Figure 1.

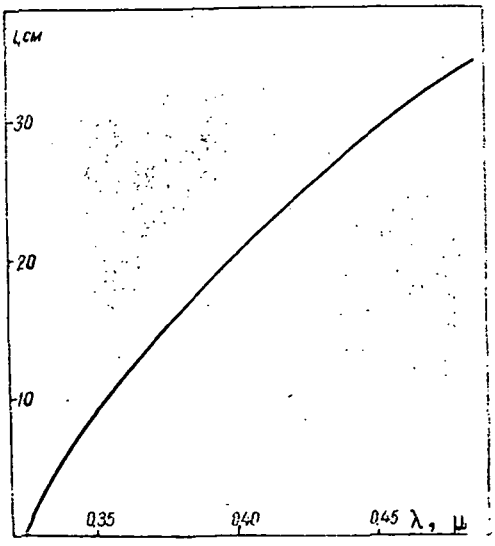

Figure 1. ASP-7 spectrograph dispersion curve.

Slit width was selected as 0.13 mm (≈2.6") for the Jupiter spectrograms. Calibration, star spectra for comparative purposes, and spectra of the Sun and of the planet, all were made and obtained at the same exposures at this slit width, and this, in our opinion, is mandatory for this type of observation. Two conditions were satisfied in the selection of the stars to be used for comparative purposes. First of all, the star, standard in order to preclude extinction, was selected for small angular distance from the planet. Second, its spectral class was selected as close as possible to that of the Sun. A star of the class

AO(η Vir) could be used as the standard when the first of these conditions was observed more closely. This latter fact proved convenient, in that the spectrograms of the planet, as well as of the comparison star, could be made at the same exposure. Moreover, the continuous spectrum suffers less distortion by absorption lines in the star of an early spectral class. The spectrograph slit was oriented so as to avoid the influence of atmospheric dispersions when obtaining star spectrograms (in the meridian perpendicular to the horizon). The comparison star then was tied to the center of the solar disk.

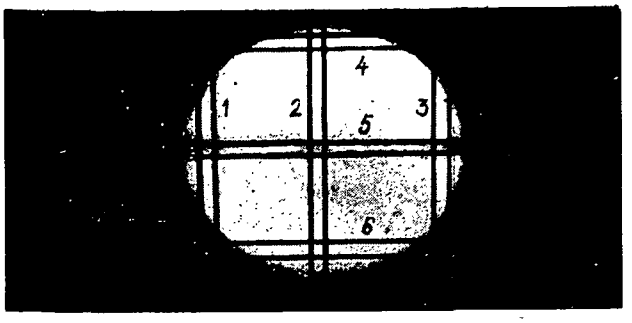

Figure 2. Orientation of slit for studying the UV absorption in Jupiter's spectrum (6 is the south polar region).

The program for one night's observations was as follows. The spectrograph slit was oriented on Jupiter's equator and along the central meridian. S and N, the polar regions, and the west and east limbs, were cut off. Figure 2 shows the position of the slit on the planet's disk. All spectrograms were obtained at the same exposures (10 sec, 30 sec, 90 sec, 3 min) for Jupiter and for the comparison star. The comparison star was observed before and after exposure (depending on the position of the planet after the upper culmination) of the particular section of the planet. It was customary to take 3 or 4 spectrograms in one night for all positions of the slit near the planet's culmination shown in Figure 2, thus providing normal density of blackening in the 3300-4800 Å region. In addition, 5 to 6 series of spectrograms were made on one plate for a particular region of the disk, and these then were used to find the observation error. Each region of Jupiter's disk, and the comparison stars, were exposed on /14 the same plate (6 to 7 spectrograms). A diaphragm with a central shutter was placed in front of the spectrograph slit. The accuracy of the 10 second exposure was of the order of 1 percent, with the accuracy of the other exposures very much better, naturally. A step attenuator was used for calibration. An

incandescent lamp, supplied from a stabilized source of supply, was used. Emulsion grade ZU-2 was selected because UV absorption in the 3300-4800 Å region was studied. The limbs of the disk were studied with the slit $r \approx 0.7R_J$ from the center of the disk.

The following considerations were involved in selecting this distance. The observations were made for zenith distances $Z \leq 50°$. Table 2 shows that when observations of polar regions of the planet are made there is a shift in the slit of 2.20" ($Z = 50°$) caused by atmospheric dispersion in the band of wavelengths we were studying. This shift actually differs from the true shift because the slit is exposed without filter. The spectrograph slit is between 0.7 and $0.85R_J$ (shift of 3") when observing the south polar region for the Z value taken. The extreme position of the slit corresponds to the distance from the center of the disk, $r_1 \approx 17"$ (~3" from the limb). This also had a hand in the selection of the height of the microphotometer window when measuring the spectrograms.

All plates were developed using D-19 developer at +19°C. We also used a special adapter so 30 plates with spectrograms of Jupiter, stars, and four calibration plates could be developed simultaneously.

Processing the Spectrograms

The first thing to be established is which of the characteristic curves to use to correctly study the continuous spectrum in the 3300-4800 Å region we selected. ZU-2 plates were studied to determine the contrast in terms of wavelength and exposure. Measurements were made every 30 Å for all exposures. The result was to establish that contrast, γ, depends on wavelength and exposure. Contrast changes slowly from 4800-4200 Å, but beginning at 4200 Å drops rapidly toward the shortwave side. In the 4500 Å region $\gamma \approx 2.00$ for exposures from 40 seconds to 3 minutes, whereas $\gamma \approx 1.60$ in this same region for exposures from 10 seconds to 30 seconds. Figure 3 shows the $\gamma(\lambda, t)$ relationship. These curves were obtained from study of 10 plates in each ZU-2 batch (three batches).

Characteristic curves then were plotted for 16 values of the wavelength (every 100 Å) with overlapping of the spectrograms at four points in the continuous spectrum (Figure 4). The curves were plotted with confidence because the scatter in the points was slight (number of points per curve 5 to 8). The spectrograms were measured by an MF-4 microphotometer with an FEU-15B photomultiplier as the radiation receiver, and darkening was recorded on recorder graph paper. The

photomultiplier supply was from a stabilized source. The measurements of the spectrograms were made along the dispersion in 16 sections of the continuous spectrum free of absorption lines. The microphotometer window cut out spectrogram sections 0.05 x 0.10 mm (5 Å/mm at 3300 Å x 8"). This window width was selected such that first, resolution of the spectrograms obtained would not deteriorate during photometry, and second to eliminate the fluctuations caused by graininess of the plates. The window height indicated was selected in order to reduce the influence of atmospheric dispersion when processing the spectrograms of the south polar region. The extreme position of the spectrograph slit near 3300 Å corresponds to $\approx 0.85R_J$. The length of the corresponding chord is 10". Thus, with a window height of 8", the influence of atmospheric dispersion on the measurement of the relative spectral energy distribution for the south polar region can be determined by the distribution of the brightness along the planet's central meridian (along the direction of the shift in the slit occasioned by atmospheric dispersion). /15

All spectrograms obtained for the same region of Jupiter's disk, but with different exposures, were subjected to photometry. Subsequent

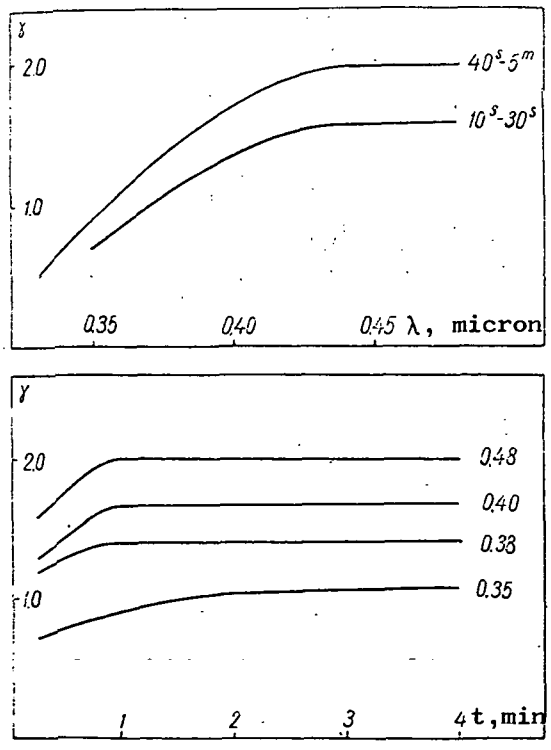

Figure 3. The $\gamma(\lambda, t)$ relationship for study of the ZU-2 plates.

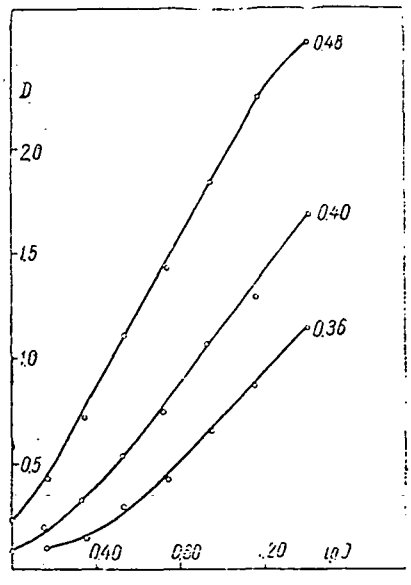

Figure 4. Characteristic curves.

processing usually used the recordings of two spectrograms that reliably overlapped the whole of the region of the spectrum studied (1-4800-3900 Å; 2-4200-3300 Å).

Thus, the photometric tie (overlap) to two spectrograms obtained with different exposures was made at four points (four characteristic curves). Finally, the recordings of blackening obtained were converted into intensity in accordance with the 16 characteristic curves in all regions of the spectrum we studied. The angular recession of η Virginis, the comparison star, from Jupiter usually was a maximum of 1° during the observations, and the time between star exposure and that of the particular region of Jupiter's disk was a maximum of 10 minutes. Hence, the values $\lg I_J - \lg I_*$ were not distorted by the influence of extinction. Although η Virginis is stationary, its photometric comparison with α Leonis, the spectral distribution for which is well known, was made in passing. As should have been expected (these stars are comparable in terms of spectral class) the energy distribution in η Virginis proved to be very nearly that for α Leonis. We deemed it undesirable to use existing data on solar spectral energy distribution to compare η Virginis with the Sun, because to do so obviously could introduce additional errors. /18 The correct tie to the Sun should be made with the same equipment for the concrete purpose of studying the planet's spectral energy distribution. We made the photometric tie between star and Sun as follows. When atmospheric conditions were favorable, and when the star observation program was completed, the sun was observed on the same morning, at the same distances as the stars.

A Hartmann diaphragm with a 3-mm diameter opening was placed over the telescope tube when observing the Sun. The working alignment of the openings was located along the refracting edge of the spectrograph prism. A 25-mm diameter diaphragm was placed in front of the hole in the main mirror to attenuate the flux of energy arriving from the Cassegrain mirror. This flux can be varied by the magnitude of the diaphragm, as well as by the distance of the diaphragm from the Cassegrain mirror.

Thus, the densities of the spectrograms of the center of the solar disk were obtained very close to those of the spectrograms of the comparison star and planet. The tie of star to Sun was made in 5 days in April 1969. The solar spectrograms obtained were measured under the same conditions as were the spectrograms of the planet. The calculations made of monochromatic intensities of Jupiter assumed, in accordance with Allen [13], a solar limb darkening, and used the formula

TABLE 2. MONOCHROMATIC VALUES OF REFRACTION FOR VARIOUS Z AND λ

Z/λ	ΔR															
	0.33	.34	.35	.36	.37	.38	.39	.40	.41	.42	.43	.44	.45	.46	.47	.48
30°	1″.01	0″.85	0″.70	0″.63	0″.60	0″.47	0″.40	0″.26	0″.10	0″.08	0″.05	0″.02	0″.01	0″.01	0″.01	0″.00
40	1 .60	1 .40	1 .35	1 .15	1 .00	0 .85	0 .75	0 .55	0 .40	0 .15	0 .10	0 .06	0 .03	0 .01	0 .01	0 .00
50	2 .20	1 .90	1 .85	1 .50	1 .40	1 .15	0 .90	0 .85	0 .60	0 .40	0 .30	0 .22	0 .14	0 .09	0 .05	0 .00
60	2 .85	2 .55	2 .35	1 .65	1 .55	1 .45	1 .25	0 .80	0 .55	0 .40	0 .28	0 .22	0 .17	0 .13	0 .10	0 .00
70	4 .47	4 .10	3 .70	3 .20	2 .70	2 .20	1 .95	1 .70	1 .30	1 .10	0 .90	0 .70	0 .50	0 .35	0 .20	0 .00

TABLE 3. ULTRAVIOLET ABSORPTION IN THE CONTINUOUS SPECTRUM OF JUPITER

Disk region number	λ, microns															
	UT	0.33	.34	.35	.36	.37	.38	.39	.40	.41	.42	.43	.44	.45	.46	.47	.48
								1969, 5.I									
1	2ʰ23ᵐ	51	54	47	47	27	33	21	13	10	05	05	06	02	04	08	0
2	2 40	11	13	14	23	09	17	04	08	05	03	01	+01	+02	01	03	0
3	2 55	33	44	48	45	37	43	33	25	24	18	11	17	10	09	07	0
4	3 15	38	54	52	54	36	33	33	31	29	19	13	14	11	06	04	0
6	3 56	77	67	52	44	42	43	35	29	25	17	13	02	02	00	00	0
								7.I									
1	0 37	40	46	37	36	38	33	28	28	26	17	04	01	+04	+03	+01	0
4	2 20	50	50	44	40	30	27	13	06	06	07	04	08	05	05	06	0
5	2 51	40	40	42	45	34	28	29	25	19	17	14	+01	01	02	05	0
6	3 02	56	51	41	45	33	30	12	04	06	06	04	03	06	05	03	0

TABLE 3 continued

Disk region number	UT	λ, microns 0.33	.34	.35	.36	.37	.38	.39	.40	.41	.42	.43	.44	.45	.46	.47	.48
								7. III									
1	21 00	+01	+01	15	10	04	11	00	07	03	03	03	01	01	+01	+02	0
2	21 23	06	20	18	25	19	26	15	20	09	08	15	05	03	02	01	0
3	21 43	28	32	35	34	24	20	16	15	18	14	12	10	04	02	02	0
4	22 58	13	08	10	06	12	17	03	01	03	01	05	03	06	+01	+01	0
5	22 27	20	26	26	31	20	19	15	15	08	08	13	+03	+02	04	01	0
6	22 06	21	29	31	34	16	22	09	15	09	08	07	02	+01	01	+02	0
								8. III									
1	22 24	17	19	26	33	25	30	18	26	16	23	15	07	05	02	04	0
2	22 41	05	05	06	22	13	16	13	29	15	10	12	07	+06	+03	00	0
3	22 54	27	27	30	35	21	16	22	17	21	18	18	16	03	04	11	0
4	21 29	07	22	15	18	18	13	11	11	05	09	08	05	03	03	+01	0
5	21 44	03	12	05	12	15	17	08	11	07	01	09	02	02	01	+01	0
6	22 04	53	48	35	31	32	30	29	13	16	16	09	10	04	00	09	0
								20. III									
1	23 14	45	52	61	57	46	49	38	30	22	14	08	06	04	01	02	0
2	23 36	32	39	34	38	33	27	27	23	16	19	11	06	01	00	01	0
4	22 47	30	53	47	36	34	36	20	16	09	10	07	00	+04	+06	+02	0
5	22 21	51	49	45	40	39	35	27	24	18	25	12	06	00	+01	+04	0
								10. IV									
1	20 00	23	28	26	32	20	19	17	14	10	08	04	03	+05	+06	+01	0
2	20 11	45	49	49	45	40	38	22	27	26	21	17	09	11	09	05	0
3	20 40	32	32	39	36	25	23	18	15	17	11	10	06	02	+01	+03	0
4	18 35	32	33	38	29	27	19	12	06	03	+04	02	02	00	+01	+03	0
5	19 03	19	22	21	30	28	33	26	24	20	14	18	08	01	01	+05	0
6	19 33	50	55	50	48	41	35	29	19	16	18	15	09	01	05	+03	0
								28. IV									
4	19 16	40	52	54	45	35	32	25	20	17	12	09	08	02	+02	00	0
5	19 39	35	37	45	41	32	28	24	26	17	19	17	10	04	00	03	0
6	20 01	47	45	52	36	38	40	30	24	19	15	09	08	01	+03	+02	0

$$\lg \frac{I_J}{I_\odot} = \lg \frac{I_J}{I_*} - \lg \frac{I_\odot}{I_*}.$$

Because atmospheric dispersion has a significant effect on spectrophotometric investigations of the planets (we have the polar regions in mind here), the formula given in reference [15] was used to calculate the monochromatic values of refraction for various Z and λ (Table 2), and these then were used to determine the magnitudes of the UV absorption for Jupiter's polar regions.

Results of Observations

Table 3 lists the results of the relative spectral energy distribution for different regions of Jupiter's disk for all dates of observations. The first column in Table 3 shows the number of the region on the planet's disk for each date and the positions of the spectrograph slit as shown in Figure 2; that is, 1- east limb; 2- central meridian; 3- west limb; 4- north polar region; 5- planet's equator; 6- south polar region. The second column lists universal time for the middle of the observation interval for each region. The table then lists 10^2[lg I(λ) - lg I(0.48)] for each wavelength in 0.1 increments. All values without signs are negative. The nature of the dependence of the monochromatic albedo of the regions of Jupiter's disk that were observed can be judged from the curves in the appendix. Figure 5 shows the combined data on relative spectral energy distribution for each region of Jupiter's disk for the whole of the observation period (January-May 1969). These curves show the difference in the reflectivity of Jupiter with respect to the spectrum for individual observation dates. Figure 5 compares the mean energy distribution curves for groups 1, 2, 3, and 4, 5, 6. Ten spectrograms were obtained in a 30 minute period on 20 March 1969, near the culmination of Jupiter with the slit oriented along the planet's central meridian, in order to determine energy distribution errors. Ten spectrograms of the comparison star were taken during this same period. Curve 1 in Figure 6 is the mean curve for Jupiter's spectral energy distribution as obtained from the 10 spectrograms. The vertical segments show the root-mean-square error in one measurement (5-7 percent). The error was found from

/20

$$\sigma^2 = \frac{\sum |\varepsilon_i|^2}{\sum n_i - N},$$

where

ε_i is the modulus of the deviation from the mean arithmetical error;

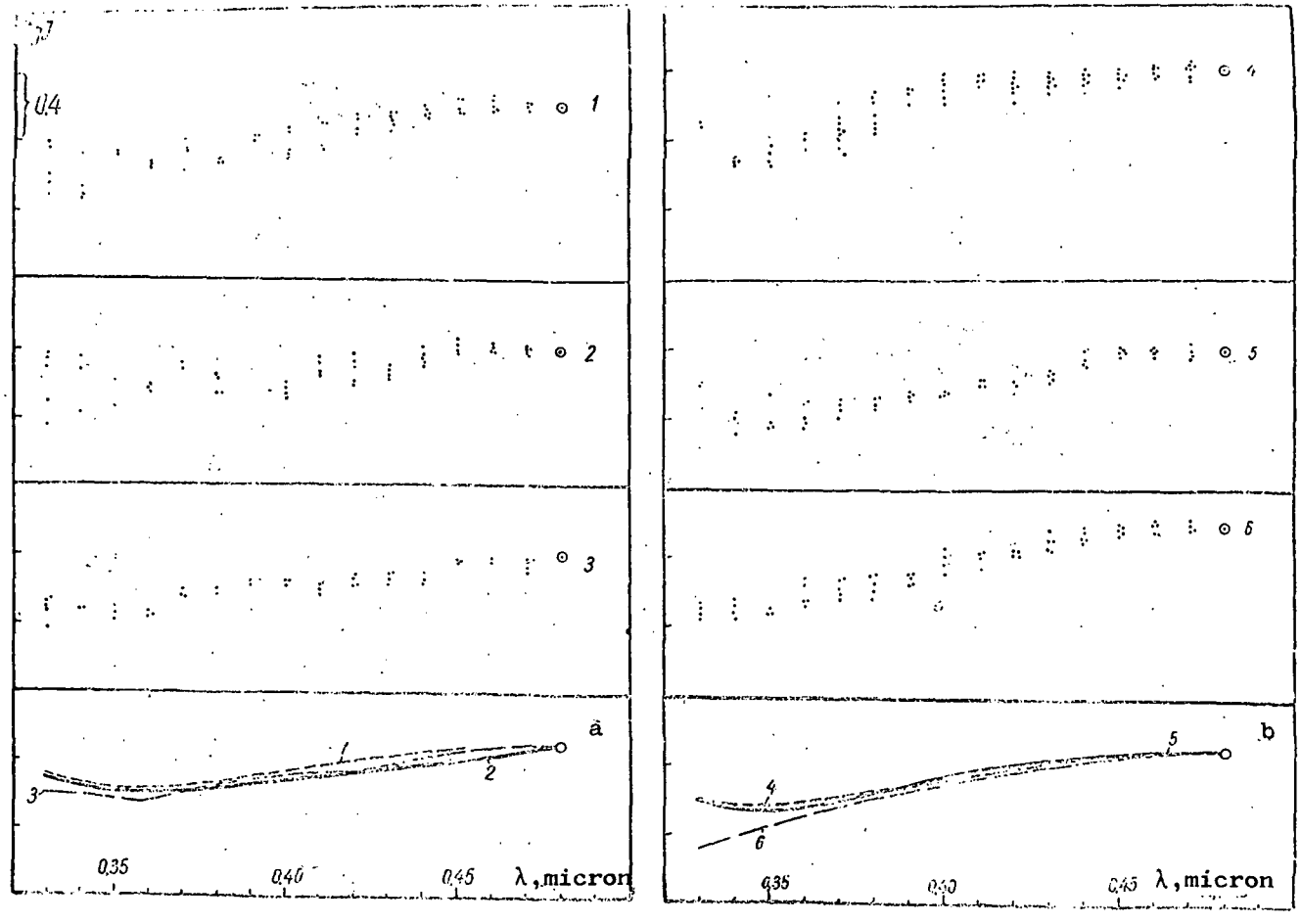

Figure 5. Comparison of mean energy distribution curves.
a- regions 1, 2, 3, 6-4, 5, 6; 1- east; 2- meridian;
3- west; 4- north; 5- equator; 6- south.

Σn_i is the total number of measurements for the spectrograms;

N is the number of points measured on each of the spectrograms.

Curve 2 in Figure 6 shows the scatter in the lg I(λ) - lg I(0.48) values, and gives some idea of the error in the behavior of Jupiter's relative spectral energy distribution (observation errors).

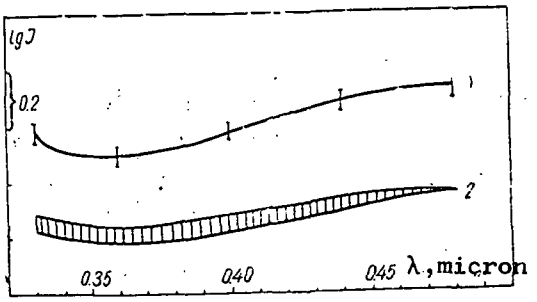

Figure 6. Jupiter's spectral energy distribution to determine observation error. 1- root-mean-square error in one measurement; 2- scatter of lg I(λ) - lg I(0.48) values during one night.

Discussion of Results and Conclusions

Our spectrophotometric study of the relative spectral energy distribution for individual sections of Jupiter's disk in the 3300-4800 Å region revealed that the existence of UV absorption in Jupiter's atmosphere is real, and as follows from Figures 5 a, b, the magnitude of the absorption effect, within the limits of observational errors, is the same for all sections of the planetary disk, on the average, as lg I(0.33) - lg I(0.48) = -0.33. The following needs consideration with respect to variations in UV absorption. Figure 6 and the appendix show that variations in the observed relative distribution of energy in the shortwave region of Jupiter's spectrum greatly exceeds observational errors from date to date. The curves for 7 and 8 March (Figure 6, 2) are much flatter than for the other dates, for example. The difference is lg I(0.33) - lg I(0.48) = -0.15 for 7 March, but is an average -0.45 for the other dates. Still, it is difficult to say that we are, or are not, dealing here with variations in the UV absorption for the same observed sections of the planet's disk (meridian, equator, west and east limbs), or whether what is involved here is that, because of the rotation of Jupiter, we observed different regions of the planet with different energy distributions (the longitudinal effect) on each individual date. Only a specially conducted sampling of lengthy, systematic,

observations can explain just how significant the latter of these is. Our observations clearly are inadequate for these purposes. Time should be taken, in particular, to determine the magnitude of the UV absorption in Jupiter's polar regions.

As will be seen from the appendix, the magnitude of the UV absorption for region 6 (south) is systematically larger than for region 4 (north). Figure 5b shows that the magnitude /21

$$\lg I(0.33) - \lg I(0.48) = \Delta I$$

is equal, approximately, to -0.5 for the south polar region, and to -0.3, approximately, for the north polar region. It already has been noted that atmospheric dispersion increases UV absorption for the south polar region, and decreases it for the north.

Let us evaluate the approximate magnitude of the effect created by atmospheric dispersion on the distribution of brightness along the planet's central meridian.

1. South polar region. According to reference [16], the distribution of brightness along the planet's meridian has little to do with the wavelength up to $r_1 = 0.85R_J$ in the 4300-6480 Å band. The brightness ratio for $r_1 = 0.85R_J$ and $r = 0.7R_J$ is close to 0.7. Considering the tendency toward some increase in this ratio on the short wavelength side, let us take $I(r_1)/I(r) \approx 0.80$, or $\lg I(r_1) - \lg I(r) \approx 0.10$, for 3300 Å.

Thus $\Delta I \approx -0.4$ for the south polar region (instead of -0.5 with the atmospheric dispersion disregarded).

2. North polar region. The brightness ratio for $r = 0.7$ and $r_2 = 0.55$ is close to 0.8, using the same measurements [16]. Let us take $I(r)/I(r_2) \approx 0.9$, or $\lg I(r) - \lg I(r_2) \approx -0.05$ for 3300 Å. Thus $\Delta I = -0.35$ for the north polar region (instead of -0.3 with the atmospheric dispersion disregarded).

The overall influence of atmospheric dispersion in the measurement of UV absorption is quite significant for the polar regions of Jupiter when the planet's zenith distance is near 50°, as we see, and the magnitude of the UV absorption is approximately the same for the north and south polar regions.

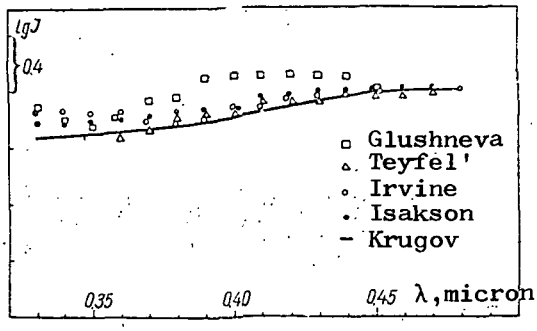

Figure 7. Comparison of our results with those obtained by other authors.

In conclusion, let us compare our results with those from similar investigations made earlier by other authors. Figure 7 shows curves of Jupiter's relative spectral energy distribution obtained by us, and by other authors (region 2, the meridian, was taken from our observations for the comparison). As we see, our data are in good concordance with the data provided by other authors, with the exception of those obtained by I. N. Glushneva, who made the observations using spectrophotometry for the entire disk.

The author is indebted to I. K. Koval' for his constant attention to the work, as well as to V. V. Avramchuk and A. V. Morozhenko for consultations.

/22

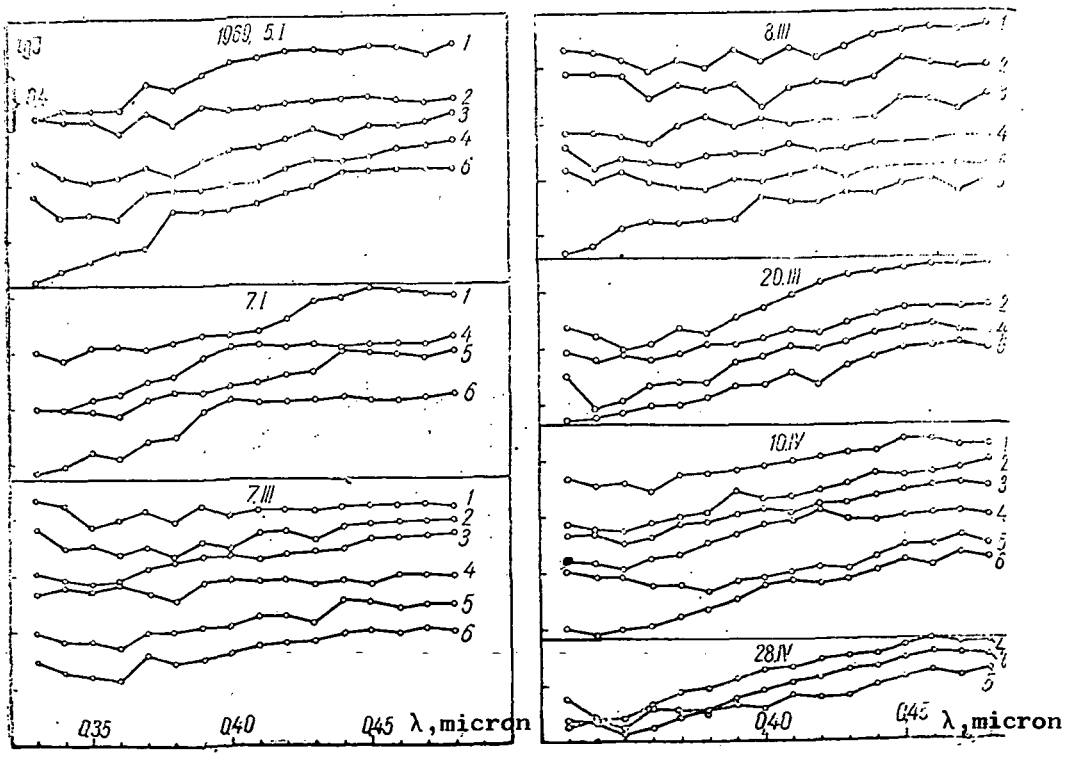

Figure 8.

REFERENCES

1. Barabashov, N. P., Chekirda, A. T., Trudy Astron. Observatorii KhGU, 1, 9, 1950, pp. 19-23.

2. Teyfel', V. G., Izv. Astrofiz. in-ta, Vol. 13, 1962, pp. 54-61.

3. Teyfel', V. G., Izv. AN Kaz. SSR, No. 1, 1963, pp. 74-77.

4. Kiess, C. C., Corliss, C. H., Kiess, H. K., Ap. J., 132, N 1, 1960, pp. 221-231.

5. Glushneva, I. N., Astron. zhurn., 41, No. 4, 1964, pp. 720-723.

6. Younkin, L., Munch, Mem. Society Roy. Sci., Liege, 7, No. 1, 1963, pp. 125.

7. Kartashov, V. F., Trudy Astrofiz. in-ta AN Kaz. SSR, IX, 1967, pp. 47-50.

8. Avramchuk, V. V., Trudy Astrofiz. in-ta AN Kaz. SSR, IX, 1967, p. 51, (thesis).

9. Isakson, M., Departamento de Astronomia, Publicaciones, No. 7.

10. Irvine, M., Aj., 73, 1968, p. 9.

11. Hopkins, B., Irvine, W. M., IAU Symposium 40, October 1969.

12. Johnson, F. S., J. Meteor, 11, 6, 1959, p. 436.

13. Allen, C. W., Astrophysical Magnitudes, 1960, pp. 167-168.

14. Avramchuk, V. V., Fizika Luny i planet [Physics of the Moon and Planets], 1968, pp. 126-160.

15. Teyfel', V. G., Trudy Astrofiz. in-ta AN Kaz. SSR, IX, 1967, pp. 98-103.

16. Lebedinets, V. N., Trudy Astron. observatorii KhGU, 12, 1957, pp. 168-239.